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Managing digital coordination of design: emerging hybrid practices in an institutionalized project setting

JENNIFER WHYTE*

Design Innovation Research Centre, School of Construction Management and Engineering, University of Reading, Reading, UK

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What happens when digital coordination practices are introduced into the institutionalized setting of an engineering project? This question is addressed through an interpretive study that examines how a shared digital model is used in the late design stages of a major station refurbishment project. The paper contributes by mobilizing the idea of 'hybrid practices' to understand the diverse patterns of activity that emerge to manage digital coordination of design. It articulates how engineering and architecture professions develop different relationships with the shared model; the design team negotiates paper-based practices across organizational boundaries and diverse practitioners probe the potential and limitations of the digital infrastructure. While different software packages and tools have become linked together into an integrated digital infrastructure, these emerging hybrid practices contrast with the interactions anticipated in practice and policy guidance and present new opportunities and challenges for managing project delivery. The study has implications for researchers working in the growing field of empirical work on engineering project organizations as it shows the importance of considering, and suggests new ways to theorize, the introduction of digital coordination practices into these institutionalized settings.

Keywords: Complex organizations, design, digital infrastructure, hybrid practices, projects.

Introduction

Digital technologies have a profound effect on the nature and structure of organizations (Kallinikos, 2006). They play a significant role in the reorganization of many broad sectors of the economy, with research describing changes in health care (Martin *et al.*, 2006), aerospace (Berente and Yoo, in press), pharmaceuticals (Nightingale, 2000) and computer hardware design (D'Adderio, 2003). In engineering project organizations, Whyte and Levitt (2011) argue that new digital practices are breaking the mould of 1960s approaches to project management, with the emergence of both highly structured centralized systems, for example, the digital integration of information in construction through 'building information modelling' (BIM) (Eastman *et al.*, 2008), and the simultaneous emergence of decentralized social networking or Web 2.0 approaches.

Researchers are now beginning to draw on organization studies and sociology to theorize digitally enabled design work on construction projects (Harty, 2005; Boland *et al.*, 2007; Hartmann and Fischer, 2007; Taylor, 2007; Bresnen and Harty, 2010; Dossick and Neff, 2010; Harty and Whyte, 2010; Tryggestad *et al.*, 2010; Whyte and Lobo, 2010). Boland *et al.* (2007), for example, track innovation on a project by the architect Gehry, arguing that use of three-dimensional (3D) digital technologies allows waves of innovation to propagate across the firms involved. Taylor (2007) identifies factors that form pre-conditions (work allocation, interdependence and current technology); that affect implementation (alignment of the innovation to project network and firm interests) and that affect acceptance (relational stability, interests, boundary permeability and an agent for change). Dossick and Neff (2010) focus on the coordination of mechanical, electrical and public health (MEP) services and posit that leadership skills enable managers in design and construction organizations to deal with the increasing tight coupling of technological

*Author for correspondence. E-mail: j.whyte@reading.ac.uk

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solutions within loosely coupled organizational structures. Hence, work in this field seeks to increase understanding of digital practices in engineering project organizations from a variety of theoretical perspectives. It provides rich empirical details and new ways to theorize consequences of new technologies, factors involved in implementation and the demands they place on organizational leaders; however, it has paid only limited attention to how highly institutionalized contexts shape the practices that emerge.

Questions about how technologies become used in institutionalized project settings are timely, as there is rapid uptake of digital practices in sectors such as construction, with a recent study in the USA, for example, noting that in 2009 half of the contractors are using digital models, a 75% increase in usage in two years (Young *et al.*, 2009). Procedures for digital design and construction are being written into public procurement in countries such as Sweden, Denmark, Norway and the USA (GSA DECA Senaatti Statsbygg, 2007). In the UK, there is a standard that defines methods for the management of production, distribution and quality of construction information (Richards, 2010), with recent government strategy including targets for progressively mandated use of collaborative BIM for government projects. Studies of innovation have tended to focus on such novelty rather than technology-in-use (Edgerton, 2007) and hence have under-represented the hybrid forms that arise as new tools become implemented; the multiple uses and the potential growth in significance of technologies as they become enmeshed in practices. In the context of digital coordination practices, there is little understanding of the diversity of organizational practices that are emerging beyond those recommended in industry and policy guidance.

This paper focuses on the question: ‘What happens when digital coordination practices are introduced into the institutionalized setting of an engineering project?’ It draws on an interpretive study that examines how a shared digital model becomes used in the late design stage of a major station refurbishment project. The implementation of such a shared digital model involves repositories for digital data, standards and protocols for the use of these data and a wide suite of computer-aided design (CAD) modelling and simulation software packages and tools (Whyte and Lobo, 2010). The rationale behind this integrated set of practices is now often described as BIM (Eastman *et al.*, 2008; Dossick and Neff, 2010). As software tools and packages have become linked together with each other and with the implementation of new practices, organization scholars have begun to theorize their role as ‘infrastructure’ (Edwards *et al.*, 2007) rather than separate ‘objects’ or ‘packages’. In this paper, the shared model is thus discussed theoretically as ‘digital infrastructure’, to emphasize the interlinked nature of the digital systems and the central role they increasingly play in design coordination practices.

The next section gives a description of the project setting and data collection and analysis processes. The findings are then summarized and discussed in the following two sections. These articulate diverse patterns of activity that emerge: (1) as, within the project team, professions develop different relationships with the shared model; (2) as the project team negotiates paper-based practices across organizational boundaries, using the shared model for the design work within the team and generating traditional deliverables for the client, local authorities and regulators and (3) as diverse practitioners probe the potential and limitations of the digital infrastructure.

Interpretative research aims to expose the reader to the rich details of the case and to use this to develop new theoretical insights (Dougherty, 2002), so the paper draws in the existing literature to develop the argument through the analysis and interpretation of the data rather than presenting it separately before describing the study. The study has implications for researchers working in the growing field of empirical work on engineering project organizations as it shows the importance of considering, and suggests new ways to theorize, the introduction of digital coordination practices into these institutionalized settings. The discussion section considers how hybrid practices emerge around the digital infrastructure that involves patterns of loose as well as tight coupling and how these contrast with the more direct interactions anticipated in practice and policy guidance. The conclusions section articulates the implications for further research, showing how the emerging hybrid practices within institutionalized project settings raise important new questions about digital coordination in engineering project organizations.

Research setting and design

The station refurbishment project

The case study that is analysed and discussed is a major station refurbishment. The work includes upgrades to the platforms, a services building, enlarged ticket hall and entrances, all for a tightly constrained site located at one of the busiest junctions in a major European capital. There are many physical interdependencies as well as tight project deadlines. Objectives include step-free access, station modernization and fire safety improvements, and hence the design work provides congestion relief/capacity enhancement, additional escalators, additional connections to platforms and improved interchange.

While the initial design was developed by a different team, the engineering design consultancy with which this study was conducted was engaged at the detail design stage to lead a multi-disciplinary team that would develop the design further and produce contract documentation. Their work on the scheme involves interaction with government bodies including the highways authority and local boroughs. The team consists of tunnels, structures and MEP engineers, with subcontractors including two architectural firms and engineers from the client. The previous scheme design, which they inherited, was drawn up in two-dimensional (2D) drawings. However, managers decided to develop the design in models rather than drawings because of the complex 3D nature of the work: at a junction located in an area with high volumes of pedestrian and vehicle traffic and design work on new facilities that join onto existing infrastructure, connecting with nineteenth century tunnels and spanning across different levels, above and below ground, and at times under existing buildings.

Sharing of data is achieved through two software packages, from a major software provider, which provides products similar to its competitors. This embeds the use of off-the-shelf packaged software solutions into the core of the delivery processes associated with the project. The packages, which are configured so that they are always used simultaneously, include:

- ‘CAD’: the base CAD package, used for both 3D modelling and the 2D drafting work.
- ‘Coordination’: the repository, in which CAD data are stored, versions are managed and workflows are applied.

The ‘Coordination’ software takes substantial work to set up for the project, whereas the CAD package is used more as an off-the-shelf package, supplemented with the software provider’s wider suite of add-on packages, with a specialist 3D modelling tool and structural, mechanical and electrical tools for various disciplines, a package for highways design and for the reinforced concrete detailing. A separate provider’s viewing software is used for viewing 3D files and for clash detection.

For project managers and other professionals working on the project, a major benefit of working in a shared 3D model is the ability to coordinate the designs of different specialists, particularly important in the MEP design and in coordinating these services with the structures. Staff working on the project bring significant experience from a wide range of other infrastructure projects as well as from other industries such as automotive and petrochemical. However, for the team as a whole, as well as for a number of engineers, CAD technicians and architectural designers, the project was their first experience in using 3D for design across all disciplines and project areas. Project managers note how the work on the project involves complex transfers of information and data in which teams are mutually dependent, uncertainty exists surrounding the design problem and potential solutions and the problem is understood by speculating and testing design solutions. The design work is conducted at the end of a boom in construction where there are real challenges of getting staff into some roles.

The office in which the design work was conducted, and in which the researcher was located when conducting fieldwork, is open plan, above the site, with views down over it. Various disciplinary teams sit together, and the central corridor through the office contain cardboard models of the enlarged station, with colour 3D printouts on the wall near the entrance to the office. Around the corner, beyond the coffee area, there is a wall that contains management information, including printed out schedules, with ink marks showing how progress is tracked against them, and risk registers for various aspects of the design. The engineering teams work full time in these offices. The architects are based part-time here, spending a few days a week back in their home offices. The client has some staff that work in this office alongside the team.

Data collection and analysis methods

Data were collected during days spent in the project office where the team was collocated. Interviews enabled the researcher to understand the novel aspects that become introduced with the use of the shared model and the challenges encountered. Being located in the project office and able to observe practice was important to see the range of tools that allow practitioners to accomplish their jobs. The study is interpretive (Silverman, 1997; Dougherty, 2002; Walsham, 2006), and hence rather than seeking statistical generalizability, it aims to build theoretical understanding of the phenomenon of the study, in this case digital coordination in institutional settings, by drawing on the observations in a particular place or time, in such a manner that this theory may be used to understand the same phenomena in other places and times. Hence, the focus is on the quality, rather than the quantity, of data and on its interpretation. There is also recognition that the researcher is a major instrument in this work of data collection and interpretation and that they always learn through the process of research. In this study, the researcher started out with substantial previous experience of research in related contexts which helped in rapidly focusing attention on the characteristic features of the case, but extended and deepened understanding through this work.

The fieldwork was conducted over a six-month period, bounded by the beginning and end of a late design stage, involved in the preparation of 'production information' (August to December 2008), though the researcher had started visiting the project as the report for the previous stage 'detailed design' was prepared (May to July 2008). To give an overview of the project, there was an initial 2 h meeting with the project manager, design manager, R&D director and rail director from the engineering design consultancy in May; materials relating to the project were then provided. The researcher was able to organize a pass and desk to spend days in the project offices through the production information stage talking to different professionals within the team about the ongoing work and conducting more formal semi-structured interviews with key members of the project team. The first point of contact was the project administrator, and by visiting the project every three to four weeks during the stage, the researcher also established an ongoing relationship with the project manager, design manager and CAD manager and other key members of the team. These professionals were interested in the research and highly reflective about their own digital practices and how they could be improved, interacting with the researcher formally and informally by email, over coffee and in meetings.

The 13 semi-structured interviews involved the project manager, design manager, project administrator, CAD manager, document controller, structures engineer, structures modeller, three architects, tunnels engineer, MEP modeller and client project manager. The research uses a well-developed interview protocol that has been used across a number of case studies (e.g. author date), with interview questions about digital packages, learning and the effectiveness of processes and systems. Interviews ranging from 40 min to 1 h were often conducted at people's desks within the office. Their semi-structured nature allowed participants to talk more broadly about their interpretations and experiences of using the shared digital model in their work, but also gave the researcher a structure to hone in on the topics of interest to the research around design coordination. As the interviews progressed, the focus was sharpened and hence in the later interviews the topics that emerged as important in the preliminary analysis were probed in more detail. As interviews were conducted in the open plan office, the interviews were not all taped (3.5 h of material was taped and transcribed). The focus was on building the trust of the participants and in taking detailed notes to capture both their and the researchers' understanding. A benefit of the location was that interviewees demonstrated issues by turning to their computer and showing the researcher aspects of their work. Although these more formal interviews were set up by appointment in advance on two occasions interviewees had also invited a colleague to join the conversation, and this sparked further useful information about the digital practices for design coordination.

Interpretative research emphasizes this value of becoming 'engaged' (Van de Ven, 2007), closely involved in the activities that are being studied and seeking to develop new understanding of these observed phenomena (Walsham, 2006). Hence, the data analysis phase overlapped with the data collection, as field notes were typed up and reread and the taped interviews were transcribed and read between days in the project. There was iteration between the focus on empirical data and literature, with summaries of interviews being sent back to participants to check and theory relating to the empirical phenomena also being explored at this stage. While software was used to track themes across the interviews, the analysis employed strategies appropriate for analysing process, rather than variance, data (Langley, 1999), with most analytic time spent rereading notes and synthesizing findings by writing narratives about the case. First, these were organized into a set of descriptive narratives that covered aspects of the organizational structure and processes for achieving design coordination, with topics from the protocol such as the use of the shared model, learning and effectiveness, and then these were further refined, reorganized and theorized. An early set of narratives was provided to the team in a 12-page summary format, and this summary was discussed in detail with project managers, who spent 2 h going through the document with the researcher. This exercise helped the researcher correct factual errors and provided further data focused on emerging themes. As is common in interpretive research, the final theoretical framing, which is described in the following sections, was developed through such analytical work. Throughout the analysis and writing process, emerging theoretical ideas raised new questions about interpretation, and there was a constant process of returning to the source data and literatures for clarification and to develop and extend explanations.

Relationships with the shared model

There is a strong contrast between the way that divisions of labour between design and modelling have become institutionalized in the architecture team and the engineering team in this setting. Institutional theorists suggest that multiple professions in a mature institutional context have deeply rooted disciplinary practices and draw on diverse cultures, meanings and values (Ferlie *et al.*, 2005; Greenwood and Suddaby, 2006; Scott, 2008). This is apparent in the way that professionals in this setting make sense of the introduction of a shared model. Architects do their own drawing and modelling work, whereas in engineering, engineers have become used to handing calculations, sketches and instructions to CAD technicians that work alongside them. Such distinctions have been studied at the time of the introduction of CAD drafting tools (Schaffitzel and Kersten, 1985; Currie, 1989; Henderson, 1999). This division of labour is replicated around the digital model, and hence the allocation of responsibilities within the sub-teams is shown in Figure 1. The boundaries between software packages indicate organizational boundaries, with the architects and engineering CAD specialists using the 'CAD' and 'Coordination' packages with specialist add-on solutions relevant to their discipline.

Engineers' lack of direct experience with the system weakens their sense of the digital infrastructure providing a shared model, or of it being centrally located between the different designers. The idea of a shared model in design coordination is not new (e.g. Anumba *et al.*, 2000), but the implementation in this institutionalized environment substantially more organizationally elaborates than the more simple

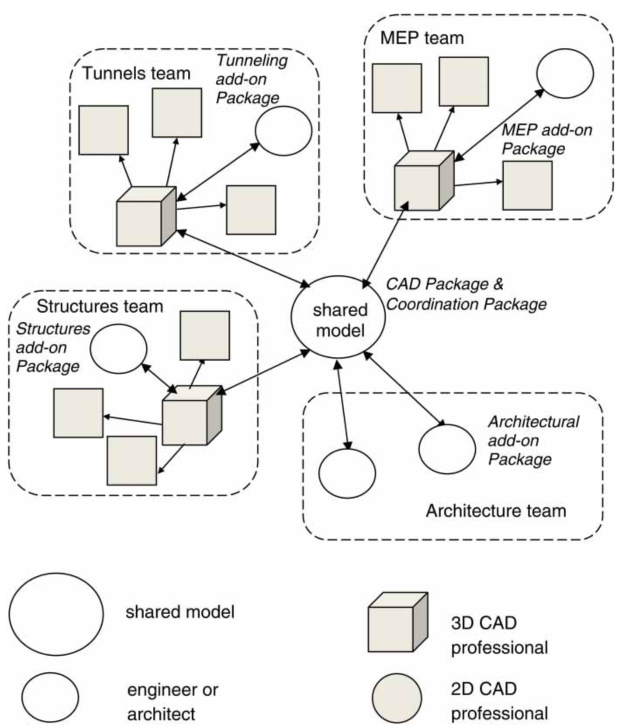

Figure 1 Different structures of responsibilities in the engineering sub-teams (structures, MEP and tunnels) and the architecture team involved in the station refurbishment project

configuration anticipated in the early research and policy documents, which envisioned each professional located around the shared model, as replicated, for example, in Smith and Tardif (2009, Figure 0.1, p. xx). Architects have direct access to the shared model and use it directly in their work, but they do not find themselves interacting with engineers who have a symmetrical relationship with it.

The plan, within the engineering disciplines (structures, MEP and tunnels), was to have one 3D modeller per discipline area and to use the 3D model to take extractions and produce drawings. This would give one person the ownership of modelling the engineering design work of each disciplinary group. However, in practice, this also causes a bottleneck in the work process, as modelling skills were in demand (and hence expensive as difficult to replicate) during the period studied (partly because of the construction boom), and the project team did not have a modeller in place in each disciplinary team throughout the stage observed. As the project CAD manager notes:

> You find that it's all well and good saying you want it in 3D, but you have also got to have the people who can use and think in 3D. I find a lot of CAD designers, CAD users are not experienced in it. Don't know how to use the software. (CAD manager)

Within engineering, this process of creating 3D models also presented new difficulties in motivating 2D CAD technicians. The engineering teams all included both 3D modellers and 2D CAD technicians, with, for example, one modeller and three to four technicians in the tunnel engineering discipline. The 2D CAD technicians take the extraction created by the 3D modeller and add any additional line work required. They are not involved in the setup, or as involved in actively thinking through the construction details, and as a result can lack a sense of fulfillment in their roles. Across the project:

> We have a team of 2–3 modelers that are basically modeling everything and they extract all the plans and sections that then go to the 2D CAD technicians to put together on drawings. The only draw-back of this is that the guy putting the drawing together doesn't have any real involvement in the design of something. (CAD manager)

During the period studied, the scarcity and status of 3D modellers were also seen as a problem by managers. For example:

> Some of them think they are too good to do the basic model. (CAD manager)

Within the project, there was an expectation that everyone would do everything, picking up the work of others to deliver design work by the agreed deadlines, but the elevated status of modellers meant that they brought a new set of expectations to their role.

Organization boundaries and emerging hybrid practices

The processes observed in this project are significantly different from those proposed in policy documents such as the standard methods (Richards, 2010), as they involve the conversion of the model back into 2D drawings ahead of the approvals and deliverable sign-off process. Although the project team is committed to a model-centric approach to design, the wider system within which they operate is institutionalized around 2D plans and sections, and they are still required to produce these for approval from regulatory bodies and as a deliverable to the client. To accommodate this, hybrid practices emerge.

Such practices bring together digital and physical media through a variety of formalized and improvized practices as 'plugging' and 'patching' take place across ecologies of practice to enable the ongoing accomplishment of work (Harty and Whyte, 2010). In the workflows within each of the engineering disciplines in the project team, new practices emerge after the modeller works with the engineer to model the design, as these models are then extracted to plans and sections that go to CAD technicians to develop into the drawings. Details are then added to the 2D drawings before issue. Design work is thus conducted using a combination of 2D and 3D, with all the 2D plans and sections coming from the 3D model. The release of information to the client and various regulatory bodies requires it to be checked, verified and approved, and the workflow is summarized in Figure 2.

Approximately 3000 drawings and documents need to be approved at the end of each stage; so in preparing the production information, the team, which had been involved since the detail design stage, was managing a project that involved 10 000 records. A 'document controller' ensures that no work goes out from the team without having been through the process. Before information is released to the client and then archived, engineers and managers should check the data and document controllers approve its release.

In effect, only the work-in-progress of each discipline is in 3D, so it becomes hard for some teams to keep the whole progress 'in synch' as changes made by engineers in the checking and approval process get made on drawings, developed by the 2D CAD professionals, and have to be put back into the model by the 3D CAD professional. The 'Coordination' package shows the workflow for each part of the model and for each drawing that comes from the model. Within it, drawings have different statuses: WIP, designer check, coordination check, manager approval, approved and issued. A major challenge discussed in interviews was that modelling in 3D takes 'a lot longer', but the team is working to the 'same time-scales as 2D'. Hence, according to an interviewee, this new way of working has long-term benefits, reducing errors on site, but there is extra work to get to the 2D plans. It is a 'larger process' but is 'worth it in the end'.

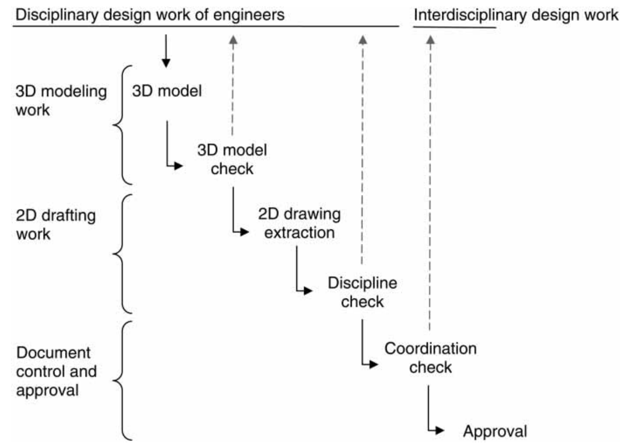

Figure 2 Design workflow from the 3D model to 2D coordination and approval in the station refurbishment project

The change from institutionalized understandings of the length of different stages of work raises additional challenges. The new processes present managers with little visibility of the completeness of the design work represented in models and drawings. This makes it difficult for them to manage client expectations, especially where the completeness of design may have contractual implications. The client manager, who was relatively new in his organization, had a perception that:

> They have delivered all their work in 2D, just basic 2D plans and sections and now they are doing the modeling after they have produced the drawings. (Client manager)

Three-dimensional modellers and 2D CAD professionals also commented that they found it more difficult to estimate time-scales; when sometimes they are asked to do things they:

> 'don't know how to do [them] so don't know how long [these things] will take.' (CAD technician)

This is a particular problem around stage deadlines, and one example given was that at the detail design deadline, when adding annotations to drawings, which should have been a 5 min job, took half a day.

As 3D information takes longer to produce than 2D information and the process involved coordinating the work of a larger number of professionals, one interviewee estimated that the production of a drawing took three to six weeks to the final 2D drawings using the new processes, whereas it would have taken two weeks to draw on a 2D basis. Another estimated that it takes a week to do what would have taken a couple of days to do on a 2D basis. In the previous stages such as detail design, resource issues, particularly difficult in obtaining and retaining 3D modellers and the departure of a services sub-consultant, meant that the model was dropping behind the design work except where there were changes that affected others.

Digital infrastructure and new practices

An ongoing process of modifying both practices and infrastructure was apparent around some limitations identified in its use of the 'CAD' package, which means it takes extra work to get 2D plans and is not just a slice through the model. The team was using the electrical/mechanical software solution, that is, an add-on to the basic 'CAD' package for the first time. When they piloted and tested it, they came across issues with the maturity of this software solution. The specialist functions supporting mechanical engineering design functioned well, but those supporting electrical design were not adequate. The software was:

> 90% complete and updating, [it] can't do what [it] says on tin. (CAD manager)

This was particularly challenging as the work 'involves processes outside of core design'. Another example was a problem with the viewing software, which could not accommodate partial updates to a model, so changes in the model needed to be re-imported and the clash detection needs to be done from scratch again.

The 'Coordination' software package also had teething problems and was overly complex though useful. One interviewee described such generic software bugs as: 'ghosts in the machine', explaining that there were changes people thought they have done ahead of a previous deadline that were not there in the system. The 'Coordination' package leaves an audit trail, but a number of interviewees pointed to issues with information going missing and corrupt files or to problems with visualizing data as the ability to print out from the system was not set up. One felt it needed a lot of customization and the Windows folder structure would be easier to use, although this would not have had the advantage of tracking file changes.

Across the team, there is significant interest in process improvement, and while this created wakes of innovation (Boland *et al.*, 2007), this was not free flowing, but rather accomplished through careful attention to the nature and effectiveness of the range of emerging hybrid practices and significant trial and error with the digital infrastructure. Some ideas were implemented through the development of new software solutions, for example, the document controller describes the implementation of new practices on the project where they:

> Happened to have an Access database developer—used her to set up a system for document tracking. (Document controller)

Other ideas were just proposed, or dreamed of, such as the idea of one member of the architectural team, who could see the value of setting parameters for tiling, etc., so that the design could be quickly changed by changing the parameters, but noted that:

> I think that's great and I'd love to be able to—the problem with that I think is if I set it up, nobody else can do it. (Architect)

This idea was not implemented as the architect anticipated a potential problem, as any other architect that might take over their role at a later stage might not understand how to use a parametric model.

Discussion: hybrid practices around digital infrastructure

A challenge for researchers is to find new ways to interrogate and understand the profound effects that digital technologies are having on the nature and structure of engineering project organizations. This study shows how the configuration of digital infrastructure, and the hybrid practices that emerge when it is implemented, becomes important in design coordination. In the project studied, management challenges related to the process or performance management become salient. The team was under pressure to deliver traditional time-scales, although it took longer to develop 3D information that could then add benefit at later stages. The digital infrastructure for delivery challenges understandings of the activities in and duration of different stages of the design process; and the deliverables it should produce. Within the project, it became difficult to find effective 3D modes of working without changing the wider institutionalized practices.

To provide practical guidance to managers, there is a need for further research to expand the examination and theorization of hybrid practices that emerge as new digital infrastructure is used in the context of institutionalized practices. The literature on institutional theory has informed this study, as well as other works on engineering project organizations (Mahalingam and Levitt, 2007). Recent work on socio-material practice and complex organizations suggests alternative starting points for this theoretical work, and these are discussed briefly here, drawing on the study and with reference to engineering project organizations.

First, the idea of socio-material practice is invoked in the phrase 'ghosts in the machine', introduced by an interviewee within the station project.[1] The inextricable nature of the social and technical has been the focus of recent research attention within organization studies and information systems (e.g. Orlikowski, 2007, 2010). In the emergent hybrid practices that evolve around digital infrastructure in the station project, the material nature of the tools with their software bugs raises issues for practice. One interpretation may be that this is an issue of implementation, something that will be worked out in later versions of the tools. For any one tool that may be the case, but here instead the interpretation is that, resonant with this wider literature on practice, innovative practices always involves these work-arounds and compromises. Hence to focus on understanding these is of ongoing relevance to our understanding of the emerging hybrid practices of design coordination.

Secondly, the literatures on complex organizations indicate paradoxical and incompatible requirements for tight coupling to deal with interdependencies ahead of time and loose coupling to deal with the exceptions arising in ongoing operations (Perrow, 1999 [1984]). A number of scholars particularly highlight organizational benefits to 'loose coupling' between elements of organization, where these elements are responsive but retain separateness and identity (Weick, 1976; Orton and Weick, 1990). In the station project, the emerging hybrid practices result in radically different patterns of loose and tight coupling in different areas of the project. This differs from Dossick and Neff's (2010) discussion of an MEP case, in which they contrast loose organizational coupling, seen as characteristic of the construction industry, and tight technical coupling, seen as characteristic of the digital coordination technologies. The alternative socio-material explanation, favoured here, is that the hybrid practices that emerge around the use of digital infrastructure involve patterns of both tightly and loosely coupled activities as attempts are made to embed new ways of working. Both studies begin to unpick the new forms of interaction and coupling that digital technologies enable (Kallinikos, 2006) with the potential for non-linear and multiple interdependencies between the different parts of engineering project organizations, and this is an area that demands further research attention.

The concepts in these literatures provide starting points for the further theoretical and empirical work needed to understand digital infrastructure in practice, to draw fine-grained research attention to how different professions structure their interaction with the integrated software, to examine how packaged software solutions and standardized packages become integrated to form digital infrastructures for delivery and, of particular concern to the project-based firms engaged in engineering projects, to understand how commercial value is obtained in this evolving area of practice.

Conclusions

This work contributes to a trajectory of research on engineering project organizations, which, informed by organization studies and sociology, is developing fresh approaches to studying digital practices in engineering projects through empirical studies that use data to shape and develop theory. The questions that this study addresses, about how practices emerge within institutionalized project settings, are important to understanding digital coordination in these contexts, as digital infrastructure is changing the nature of professional work and the organization of design in engineering projects. The paper contributes by mobilizing the idea of 'hybrid practices' to understand the diverse patterns of activity that emerge to manage digital coordination of design.

The relationships that emerge between various professionals and shared digital model are not as symmetrical or as static as implied by idealized charts in industry and policy documentation. Document controllers, CAD managers, 3D modellers and 2D CAD technicians are among the new roles in the modern design office. The engineering project organization operates within a wider set of institutionalized practices, which include formats for delivery, building regulations, local authority permissions and construction schedules, and workflow has to acknowledge the formats required for approvals and deliverables within this wider context.

This paper attempts to keep visible the physical context of the engineering project team's work, collocated in a project office above their station refurbishment site, while analysing the emergent digital practices. It articulates how engineering and architecture professions develop different relationships with the shared model; the design team negotiates paper-based practices across organizational boundaries and diverse practitioners probe the potential and limitations of the digital infrastructure. Though work has a focus on the centralized systems that are being put into place in engineering projects, there is a need for further research that considers the wide range of social networking and Web 2.0 software that is increasingly being used alongside such systems.

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Note

1. The phase references, perhaps unwittingly, Ryle's (1949) critique of Descartes mind/body dualism. The idea was later taken up by Koestler (1990 [1967]) who describes the human brain as developed on simpler material structures that act in such a manner that they are perceived without being consciously observed.

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